BOLL WEEVIL KILL RATES BY GIN PROCESSING AND BALE COMPRESSION

S. E. Hughs, C. B. Armijo, R. T. Staten

ABSTRACT. *Although the boll weevil (Anthonomus grandis grandis Boheman) has been eradicated over much of the U.S. cotton production area, there are still cotton production areas that are infested. As a result, USDA, Animal and Plant Health Inspection Service (APHIS) has procedures in place to keep the weevil from being reintroduced into eradicated areas as well as being transported overseas to cotton growing areas in other countries. Included in the procedure is the fumigation of baled cotton with methyl bromide prior to shipment. Methyl bromide may not be available as a fumigant in the near future and the fumigation process is expensive. Research was done at the USDA, ARS, Southwestern Cotton Ginning Research Laboratory to determine the actual re-infestation risk from live boll weevils processed through the normal cotton ginning and baling systems in the United States. Two tests were done: 1) a gin process survival test, and 2) a bale compression survival test. No weevils survived processing through a saw gin stand and one saw-type lint cleaner. In addition, most weevils were immediately killed at compressions of 352.4 kg/m^3 (22 lb/ft^3) and higher in the bale press. There were also no survivors after six days at the specified UD bale density of 448.5 kg/m^3 (28 lb/ft^3). Test results showed it was extremely unlikely that a live boll weevil could survive both gin processing and bale compression.*

Keywords. *Boll weevil, Ginning, Bale press, Lint cleaning.*

The spread of agricultural insect pests from infested to non-infested areas by natural causes and the movement of infested equipment or products has always been a concern to the U.S. farming industry. Cotton pests like the pink bollworm [Pectinophora gossypiella (Saunders)] have been introduced from other countries into the United States and have caused serious economic damage in certain parts of the cotton belt (Hughs and Staten, 1995). The USDA Animal and Plant Health Inspection Service (APHIS) has quarantine and cotton trash treatment regulations that certain segments of the cotton industry must meet in order to curb the movement of pink bollworm from infested to non-infested areas within the continental United States. Part of the APHIS regulations and control methods account for the fact that the mechanical ginning process is highly effective in destroying pink bollworms.

Research has shown that the seed cotton cleaning equipment used in cotton gins to clean mechanically harvested seed cotton prior to ginning is very effective in killing a large percentage of the pink bollworm brought to the gin from the field (Graham et al., 1967). Subsequent processing of the ginned lint through saw-type lint cleaners kills any remaining pink bollworm that made it through the gin stand into the ginned lint (USDA ARS, 1963). This information allows bales of ginned cotton to move freely in trade channels without fear of spreading pink bollworm to non-infected areas. Other research has shown that the proper use and design of gin trash handling fans will eliminate live pink bollworm in gin trash (Hughs and Staten, 1995; Robertson et al., 1959). This eliminates or reduces the survival and spread of pink bollworm through trash piles at gins and trash disposal in bollworm affected areas.

The boll weevil (Anthonomus grandis grandis Boheman) is another introduced cotton pest. The boll weevil eradication program has eliminated the boll weevil from large areas of the Cotton Belt that were once generally infested. APHIS and other agencies have procedures in place to keep the weevil from being reintroduced into these eradicated areas in the United States. Additionally, other cotton growing countries, that currently do not have the boll weevil, have a concern with the boll weevil being introduced by shipment of baled cotton from the United States. Current shipping and quarantine regulations include fumigation of baled cotton with methyl bromide prior to shipment to foreign ports. Methyl bromide may not be available for use as a fumigant in the near future and alternate means of treatment or verification for boll weevil free certification by APHIS will need to be found.

APHIS contacted the USDA, ARS, Cotton Ginning Laboratories at Mesilla Park, New Mexico, and Lubbock, Texas for help in establishing the survival rate of boll weevils in current cotton harvesting and ginning systems. The information was needed by APHIS to help determine if alternative treatment methods to methyl bromide are necessary to prevent boll weevil spread by means of baled cotton. Research studies were started and coordinated by both labs to look at different aspects of the harvesting and ginning processes using differing approaches. Brashears et al. (2002) conducted a study that indicated that weevils could survive

Article was submitted for review in December 2003; approved for publication by the Power & Machinery Division of ASABE in September 2005.

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U. S. Department of Agriculture.

The authors are **Sidney E. Hughs, ASABE Member Engineer,** Research Leader, **Carlos B. Armijo, ASABE Member,** Research Textile Technologist, USDA, ARS, SPA, Southwestern Cotton Ginning Research Laboratory, Mesilla Park, New Mexico; and **Robert T. Staten,** Entomologist, USDA, APHS, Phoenix, Arizona. **Corresponding author:** Sidney E. Hughs, Southwestern Cotton Ginning Research Laboratory, P.O. Box 578, Mesilla Park, NM 88047; phone: 505-526-6381; fax: 505-525-1076; e-mail: shughs@nmsu.edu.

in full size Universal Density (UD) bales up to a density of approximately 512 kg/m^3 (32 lb/ft^3). A UD cotton bale is the standard bale package produced by 100% of the commercial cotton gins in the United States. This study was conducted by putting live weevils in cotton pouches that also contained cotton fiber. The pouches were easily retrieved after compression and the weevils counted. There is some question as to whether the pouches and their additional fiber contents cushioned and protected the weevils. A following study by Sappington et al. (2003) focused on the possibility of transporting weevils to the cotton gin in cotton modules and the effects of processing gin trash, containing live weevils, through a trash fan on weevil survival. Sappington et al. (2003) also evaluated some aspects of weevil survival during ginning and lint cleaning. However, because of the method of weevil induction into the gin stand, relatively few weevils went through the gin stand and into the following lint cleaner. Sappington et al. (2003) indicated very low probability for the boll weevil to survive either the seed cotton harvesting and transport system, or processing through a trash fan.

This article reports on research conducted at the USDA-ARS, Southwestern Cotton Ginning Research Laboratory, Mesilla Park, New Mexico during the 2000-2001 harvest season. The research objective was 1) to determine the probability of a known number of live boll weevils surviving the gin stand, lint cleaner, and bale press portions of the cotton ginning system, and 2) to determine the risk of weevil survival in UD bales of differing density for both short- and long-term periods of time. If it can be established with great certainty that baled lint processed through the ginning, lint cleaning, and baling system does not contain live boll weevils, then baled U.S. cotton can be certified weevil free by APHIS based only on the mechanical process. Alternately, it would be important to determine the possibility of boll weevil or other insect pests being introduced into the United States through baled cotton from foreign cotton-growing areas.

Experimental Procedures

U.S. cotton production is highly mechanized, with all cotton processed through a number of gin machines including a gin stand and at least one lint cleaner. However, a significant amount of foreign cotton is hand-picked and may receive little processing through any gin machinery except for a gin stand and a bale press. This test was conducted primarily to determine the survival rate of weevils processed through a commercial U.S. ginning plant. It was also desirable to determine if weevils could survive in bales of hand-picked cotton from a foreign country and shipped into the United States. It was therefore necessary to investigate what might occur in the ginning system separate from the baling operation. The research was broken into two parts: 1) evaluation of live weevil survival through a gin stand, one saw-type lint cleaner, and the bale press (the minimum machinery sequence in the United States), and 2) evaluation of live weevil survival over a range of compressive forces (as indicated by density) in a cotton bale. All of the weevils used in the test were obtained live from two sources. The majority were from a lab-reared colony in the USDA, APHIS Pest Detection Diagnostics and Management Laboratory and some from local field locations. The weevils from field locations were collected in traps over a one- to two-day period and held at 2°C to 3°C (36°F to 38°F) until they were sorted and used in the test.

Gin Process Survival Test

A 93-saw Continental saw-gin stand and one saw-type lint cleaner was selected as the test ginning sequence. It is at the gin stand that the fiber is separated from the seed and sent to be packaged. After the gin stand, the only other opportunity to kill any boll weevils that might be with the ginned fiber prior to the bale press is at the lint cleaner. All saw-gin stands in the United States are followed by one or more saw-type lint cleaners prior to the bale press. A single saw-type lint cleaner was selected as the minimum machinery sequence that a live weevil might be subjected to between the gin stand and the bale press in the United States.

The expected boll weevil content for a given quantity of seed cotton being fed into a saw gin stand is unknown. Slosser (1996) reported a high of approximately 5 weevils per 3.96 m (13 ft) of row length in late August in late planted cotton (the worst case). The rate of weevil infestation then dropped off to about 3 weevils per 3.96-m (13-ft) row as the cotton moved into harvest season. This worst case scenario, assuming a 1.02-m (40-in.) row spacing, works out to be a field infestation of approximately 1000 weevils per 0.405 ha (1000 weevils per acre). Cotton production areas across the U.S. Cotton Belt vary from dry land to irrigated with lint yields that vary from 0.5 to 3+ bales per 0.405 ha (1 acre). Arbitrarily assuming a machine-picked yield of one 218 kg (480 lb) bale per 0.405 ha (1 acre) and a ginned lint turnout of 34% requires a harvested seed cotton yield of 1581 kg/ha (1412 lb/acre). If 100% of the weevils were harvested with the seed cotton and brought to the gin, there would be approximately 0.7 weevils per 0.45 kg (1 lb) of seed cotton entering the ginning system. Because it was desired to cover the absolute worst case of weevil infestation, an infestation rate of 5 weevils per 0.45 kg (1 lb) of seed cotton was used for the test. Three separate ginning lots of 91 kg (200 lb) each were processed that used a total of 272 kg (600 lb) of seed cotton and 3000 weevils for the entire ginning test.

The 93-saw gin stand used for the test operated at a rate of approximately 4 bales/h. At this ginning rate, the 91 kg (200 lb) of seed cotton took approximately 2 min to be processed and resulted in approximately 32 kg (70 lb) of ginned lint at the bale press.

The process of separation of the fiber from the seed by the gin saws occurs in the gin stand in what is known as the seed roll. It is in the seed roll that any live weevils would be killed by the gin saws. To estimate the proportion of weevils killed by the ginning process, it was necessary to be certain that all 1000 weevils per ginning lot were placed in the seed roll and exposed to the ginning process. This was done by placing 60 to 70 live boll weevils at a time in the center of a grapefruit sized mass of seed cotton. The weevils were chilled to approximately 4°C (40°F) so that they were not active enough to fly away and would stay in the center of the seed cotton mass for a short time. Each of these seed cotton masses containing the weevils were then hand placed directly into the seed roll at various locations during each 2-min ginning lot. The weevils were coated with red fluorescent dust (test weevils) to make them more easily detected through the ginning process.

After each 32 kg (70 lb) of ginned lint was processed, it was lightly pressed, tied and wrapped, and then removed from the bale press for later examination for weevils. As a check for efficiency of search, 100 dead whole weevils were dusted with orange fluorescent powder (control weevils) and were randomly placed through each lot of ginned lint prior to it being tied and removed from the press. Random placement was done by one person peeling back layers of fiber throughout the lot and another person distributing approximately five weevils at a time across the interior surfaces that were exposed. Each of the three 32-kg (70-lb) ginning lots of fiber was subsequently manually examined under a black light for both red (test) and orange (control) weevils.

In addition to the ginned lint, all of the seed, huller front trash, upper and lower motes, and lint cleaner trash was caught, bagged, sealed, and stored. This material was examined under a black light for test weevils to determine what proportion of boll weevils were removed from the lint stream at these points during the ginning and lint cleaning process. Some of the seed and trash samples were stored for up to one year before all the hand examination and counting was complete. Because of the long storage time, many weevils that could have been originally alive in the seed and gin trash would have died in the interim between ginning and final examination. Therefore, any whole weevil found in any of the seed or trash samples were assumed to have survived and counted as live.

Bale Compression Survival Test

A static restraint range of bale density from 224 to 512 kg/m^3 (14 to 32 lb/ft^3) was used for testing. This covers the range of cotton bale densities that are currently traded on the world market. The industry target density and weight of U.S. UD bales is 448 kg/m^3 (28 lb/ft^3) and 217 kg (480 lb), respectively. Lighter bale densities and weights are produced in other parts of the world. It was not practical to use full size cotton bales for this test due to press capacity and handling problems. A small laboratory model fixed volume press was used that made bales with dimensions of 13.1 $\times$ 6.8 $\times$ 6.2 cm (5.2 $\times$ 2.7 $\times$ 2.4 in.). The model press was originally constructed at the laboratory to make small souvenir cotton bales and has the hydraulic capacity to make small bales whose density exceeded that of standard UD cotton bales.

Each density level had two treatment scenarios. These treatments were called short- and long-term survival. For each density level two small bales were made and randomly assigned to either short- or long-term survival testing. For the short-term survival test, the bale was compressed and held for one minute. At the end of one minute the pressure was released and the surviving weevils were immediately counted. The procedure for the long-term survival test was to compress the bale and then tie it to maintain its compression density. The long-term survival bale was then tagged and stored at room temperature in a wire insect enclosure (to trap any weevils that might have escaped from the bales) for a period of 6 days before the bale was opened and the weevils examined for survivors.

For each test run, 20 live boll weevils were manually placed in the center of each test mini-bale. Since a fixed volume was used, the density was varied by pressing differing weights of fiber for each density level. For each test lot, the total amount of cotton fiber was weighed and then split in half. Half of the cotton fiber was placed flat in the bale chamber. Twenty boll weevils were then randomly scattered across the surface of the cotton in the bale chamber. The other half of the fiber lot was then placed into the chamber and the whole lot was immediately pressed to form a mini-bale. The weevils were kept slightly chilled at 4°C (40°F) during testing to prevent them from actively flying or escaping from the bale chamber.

Control samples of weevils were kept aside for both the short- and long-term survival tests. Before running each replicate, weevils were manually counted out in lots of 20 and placed in small transparent plastic vials. Enough weevils were counted to use in the compression tests as well as to have one control lot of 20 weevils for each of the short- and the long-term survival replicates. The control lots were handled and stored in exactly the same way as the test lots except that they were not compressed. The control lots were examined for live weevils at the same time as their respective short- or long-term survival replicate was examined.

The method of examining weevils for survival for all lots was to open the mini-bale and remove each weevil from the bale with a pair of tweezers. Each weevil was examined for signs of life, primarily movement, and those judged “dead” were placed back into the original vial and capped. The live weevils were killed by putting them into a mixture of warm water and common household liquid detergent. The numbers of live and dead weevils were recorded. The vials were stored for 24 h under room conditions and the “dead” weevils were reexamined for signs of life. Weevils have a tendency to become motionless when being handled and so must be left alone on the examining area and carefully watched for several minutes to verify their condition and/or stored for a longer period of time and reexamined. If additional live weevils were found after the 24-h storage, the numbers were adjusted (this happened very infrequently during the test) and the weevils were disposed of as before.

The compression tests were done in two different series at two different times. Figures 1 and 2 show the results of these two test series. The initial series (first test) was done over a density range of 224 to 448 kg/m^3 (14 to 28 lb/ft^3). Results of the first test indicated that the upper range should be extended to 512 kg/m^3 (32 lb/ft^3) as one weevil survived the long-term density of 448 kg/m^3 (28 lb/ft^3). The second series (second test) began at 352 kg/m^3 (22 lb/ft^3) and ended at 512 kg/m^3 (32 lb/ft^3). This range better approximates the densities that would be encountered by a boll weevil in the bale press of a

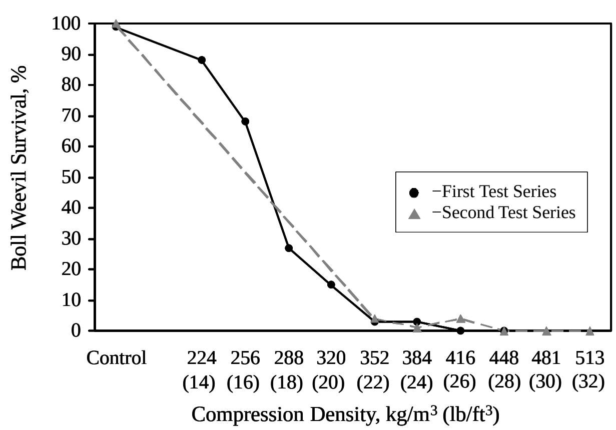

Figure 1. Short-term weevil survival vs. compression level.

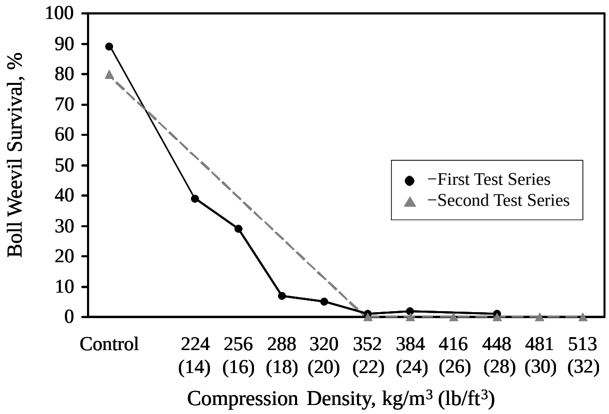

Figure 2. Long-term weevil survival vs. compression level.

commercial cotton gin in the United States. Densities varied by increments of 32 kg/m^3 (2 lb/ft^3) over the selected ranges. The statistical design for both test series was a complete randomized design, with five replications per density level.

One weevil surviving at the 448-kg/m^3 (28-lb/ft^3) compression density for six days whereas no short-term weevils survived for 1 min at this same density (see figs. 1 and 2) seemed to be an anomaly. Subsequent examination of the particular bale holding the live weevil as well as other bales in the series indicated that the manual loading of the cotton lint into the mini-bale press may not have been as evenly done as would be expected in a full size bale. A decision was made to repeat the test series at the higher densities with more realistic fiber loading into the mini-bale and drop this one data point from the analysis.

Statistical Analysis

The number of surviving weevils in each run of the experiment was modeled with logistic regression (Allison, 1991). The odds of weevil survival were modeled using 384 kg/m^3 (24 lb/ft^3) as the minimum reference compression since 384 kg/m^3 (24 lb/ft^3) was the maximum pressure where some survival occurred [i.e., all odds ratios have the odds of survival at 384 kg/m^3 (24 lb/ft^3) as the denominator].

Test Results

Gin Process Survival Test

Manually examining the ginned lint for weevils required a minimum of 150 man hours per 32-kg (70-lb) lot. With the exception of one badly mangled weevil found in the second ginning lot, nothing but small body fragments or red stained cotton fiber were found in the ginned lint (bale press location) for any of the three ginning lots (table 1). The efficiency of detection, as estimated by the percentage of orange control weevils found, was approximately 90%. A total of 3000 weevils were introduced into the process at the gin stand. If only 1%, or 30 weevils, had made it through the ginning process into the baled lint, the efficiency of detection estimate would indicate that a total of 27 weevils would have been found. The one weevil found in the second ginning lot was dead and was obviously missing three legs. Closer examination by an entomologist determined that even if the weevil had been alive and had been able to survive storage for a period of weeks or months inside the bale, it would have been

Table 1. Gin process weevil survival percentage.

Location	Average of Whole Test Weevils Found	Average of Control Weevils Found	Standard Deviation of Mean[a]
Bale press	0	90.3	3.7[b]
Huller front[c]	0.4	NA[d]	0.08
Lower motes[c]	0.2	NA	0.24
Upper motes[c]	0	NA	−
Lint cleaner trash	0	NA	−
Seed	13.8	NA	3.4
Total seed & trash	14.4	NA	3.5

[a] Standard deviation is for whole test weevils unless noted otherwise.
[b] Standard deviation of the average of control weevil percentage.
[c] Gin stand trash location.
[d] NA = not applicable.

incapable of functioning because of extensive mechanical damage.

Examination of the ginned seed and the huller front, lower mote and upper mote trash from the gin stand showed that 14.4% ± 3.5% (table 1) of the total whole weevils fed into the gin stand survived in the seed, huller front and lower mote trash. Most of the whole weevils were dead at the time of examination, but no effort was made to distinguish between live and dead whole weevils as mentioned earlier. Most of the whole weevils were found in the seed (13.8% ± 3.4%). Only small body parts were found in the lint cleaner trash for any of the ginning lots. All of the seed and gin stand trash also had many large and small body parts per test lot.

Compression Survival Test

Figures 1 and 2 show the results of the survival compression tests as percentage of survival versus compression density for the short- and long-term, respectively. The short-term test shows that a significant percentage of weevils can survive densities up to 320 kg/m^3 (20 lb/ft^3) for at least 1 min. At densities of 352 kg/m^3 (22 lb/ft^3) and higher, most of the weevils are immediately killed by the compression. Table 2 shows the results of logistic regression analysis (Allison, 1991) of the first short-term compression test. There was a complete separation in response above 384 kg/m^3 (24 lb/ft^3) as 100% of the weevils were killed. The

Table 2. First test series short-term compression analysis.

Bale Density kg/m^3 (lb/ft^3)	Weevils Surviving %	Odds Ratio Estimates[a]			
		Effect of Density kg/m^3 (lb/ft^3)	Point Estimate	95% Wald Confidence Limits	
Control (0)	96	0 vs. 384 (0 vs. 24)	775.931	169.151	>999.999
224 (14)	88	224 vs. 384 (14 vs. 24)	237.092	64.770	867.873
256 (16)	68	256 vs. 384 (16 vs. 24)	68.703	20.216	233.484
288 (18)	27	288 vs. 384 (18 vs. 24)	11.958	3.492	40.944
320 (20)	15	320 vs. 384 (20 vs. 24)	5.705	1.597	20.383
352 (22)	3	352 vs. 384 (22 vs. 24)	1.000	0.197	5.077
384 (24)	3	NA[b]	NA	NA	NA
448 (28)	0	NA	NA	NA	NA

[a] Odds ratio estimates are evaluated at the different densities relative to the 384-kg/m^3 (24-lb/ft^3) density.
[b] NA = not applicable.

control weevils had an almost 800 times better chance (776 odds ratio point estimate) of surviving than did the weevils baled at a density of 384 kg/m^3 (24 lb/ft^3). In the short-term test all the lower pressure densities had significantly higher weevil survival than at a density of 384 kg/m^3 (24 lb/ft^3) [$p < 0.007$ for all densities 0 to 320 kg/m^3 (0 to 20 lb/ft^3)] with the exception of 352 kg/m^3 (22 lb/ft^3) ($p = 0.99$).

Table 3 shows a similar analysis of the first long-term compression test. In general, the response of weevils over the longer six-day test period was similar to the short-term test except that fewer survived the long-term test. A weevil was approximately 400 times (396 odds ratio point estimate) more likely to survive at 0 kg/m^3 or control density than it was at 384 kg/m^3 (24 lb/ft^3) ($p < 0.0001$). As the density increased, weevils were less likely to survive. Survival at 288, 320, and 352 kg/m^3 (18, 20, and 22 lb/ft^3) were not statistically different ($p = 0.11$, 0.26, 0.56, respectively) from survival at 384 kg/m^3 (24 lb/ft^3) (note the confidence limits overlap 1, which is another indication that survival odds at 288, 320, and 352 kg/m^3 (18, 20, and 22 lb/ft^3) were not statistically different; a result due to small number of sample runs in the long-term compression test.

Table 4 shows the statistical analysis of the second test series. Figures 1 and 2 also show data regarding the second test series for both the short- and long-term compression tests, respectively. In the second study 100% of the weevils were killed at densities greater than 416 kg/m^3 (26 lb/ft^3) for the short-term compression test. Only the control group showed significantly greater survival rate than survival at the reference density of 384 kg/m^3 (24 lb/ft^3) ($p < 0.0001$). Because of the 100% kill at the three highest short-term densities and at all of the long-term densities, it was not possible to get numerical survival odds for these classification categories.

Discussion and Summary

The gin process test demonstrated that the mechanical action of the gin stand and the saw-type lint cleaner reliably destroyed and eliminated live boll weevils even when present in seed cotton at very high dosage levels. At the dosage rate of 3000 total weevils in 272 kg (600 lb) of seed cotton, only one partially intact weevil body made it through to the bale press. The relatively high percentage of search efficiency, as documented by the control weevils, makes it highly unlikely that any whole weevils were present in the ginned fiber lots. The one partially intact weevil found was dead and had suffered serious physical damage so that it would not have been viable even if alive. A concentrated effort was made to get a known number of live weevils into the gin stand bypassing the seed cotton cleaning section of the ginning system. It is likely that the seed cotton cleaning process would remove most weevils prior to the gin stand (Sappington et al., 2003), making it even less likely that a functional boll weevil would survive the ginning and lint cleaning process.

Table 3. First test series long-term compression analysis.

Bale Density kg/m^3 (lb/ft^3)	Weevils Surviving %	Odds Ratio Estimates[a] Effect of Density kg/m^3 (lb/ft^3)	Point Estimate	95% Wald Confidence Limits	
Control (0)	89	0 vs. 384 (0 vs. 24)	396.455	85.527	>999.999
224 (14)	39	224 vs. 384 (14 vs. 24)	31.328	7.301	134.426
256 (16)	29	256 vs. 384 (16 vs. 24)	20.014	4.624	86.620
288 (18)	7	288 vs. 384 (18 vs. 24)	3.688	0.747	18.211
320 (20)	5	320 vs. 384 (20 vs. 24)	2.579	0.488	13.617
352 (22)	1	352 vs. 384 (22 vs. 24)	0.495	0.044	5.548
384 (24)	2	NA[b]	NA	NA	NA
448 (28)	1	NA	NA	NA	NA

[a] Odds ratio estimates are evaluated at the different densities relative to the 384-kg/m^3 (24-lb/ft^3) density.
[b] NA = not applicable.

Table 4. Second test series short- and long-term compression analysis.

Bale Density kg/m^3 (lb/ft^3)	Short-Term Weevils Surviving, %	Long-Term Weevils Surviving, %
Control (0)	100	80
352 (22)	4	0
384 (24)	1	0
416 (26)	4	0
448 (28)	0	0
480 (30)	0	0
512 (32)	0	0

The compression tests showed that most weevils are immediately killed above bale densities of 352 kg/m^3 (22 lb/ft^3). The second series of tests showed that there were no survivors after 1 min at the standard UD bale density of 448 kg/m^3 (28 lb/ft^3) and there were no survivors after 6 days at densities of 352 kg/m^3 (22 lb/ft^3) and higher. Typically, cotton bales are shored for several weeks and probably for several months before being broken open and used. This length of time would make weevil survival even less likely.

In summary, the probability of a live weevil making it through the ginning system in the United States and into a cotton bale is extremely small. Furthermore, the chance of a live weevil surviving long term in a standard UD bale of 448-kg/m^3 (28-lb/ft^3) density is extremely unlikely. This test, as well as the companion tests performed by Brashears et al. (2002) and Sappington et al. (2003), demonstrates there is very little probability that a live weevil could be transported and released to infest another area or country from a normal full weight UD cotton bale. Another safety factor is that at the time of strapping, a 218-kg (480-lb) UD bale is momentarily compressed to a density greater than 481 kg/m^3 (30 lb/ft^3) in order to apply the ties. After tying, the bale is released to a nominal restraint density of 448 kg/m^3 (28 lb/ft^3). The extra compressive forces at tying will further decrease the risk of weevil survival.

There is a risk of weevils surviving if introduced in underweight U.S. bales even if tied in a UD press or in bale packages such as flat or modified flat whose normal densities are approximately 224 kg/m^3 (14 lb/ft^3). There are no modified flat bales currently produced in the United States, but this type of bale package is still produced overseas. If there is concern about introducing boll weevils into a weevil free area through the shipping of cotton bales, a restriction on underweight UD bales or any bale design with standard densities less than 320 to 352 kg/m^3 (20 to 22 lb/ft^3) would be a possible and important control factor.

ACKNOWLEDGEMENT

The authors would like to thank Sara Duke, USDA, ARS, Southern Plains Area Biometrician/Statistician for her help in data analysis.

REFERENCES

Allison, P. 1991. *Logistic Regression Using the SAS System, Theory and Application*. Cary, N.C.: SAS Institute Inc.

Brashears, A. D., R. V. Baker, T. W. Sappington, S. Carroll, M. Arnold, and M. Parajulee. 2002. Boll weevil survival in baled lint. In *Proc. of the Beltwide Cotton Conferences*, CD-ROM. Memphis, Tenn.: National Cotton Council of America.

Graham, H. M., O. T. Robertson, and V. L. Stedronsky. 1967. A method of evaluation of cotton gins for pink bollworm kill. USDA-ARS, Report No. ARS 33-121. Washington, D.C.: USDA-ARS.

Hughs, S. E., and R. T. Staten. 1995. Pink bollworm mortality using large-diameter gin-trash fans. *Applied Engineering in Agriculture* 11(2): 281-284.

Robertson, O. T., V. L. Stedronsky, and D. H. Currie. 1959. Kill of pink bollworms in the cotton gin and the oil mill. USDA-ARS Production Res. Report No. 26. Washington, D.C.: USDA-ARS.

Sappington, T., A. D. Brashears, M. Parajulee, S. Carroll, and M. Arnold. 2003. Modules, gins and the threat of boll weevil introductions: what we know so far. In *Proc. of the Beltwide Cotton Conferences*, 1329-1339. Memphis, Tenn.: National Cotton Council of America.

Slosser, J. E. 1996. Cultural control of the boll weevil – a four season approach. In *Proc. of the Beltwide Cotton Conferences*, 800-804. Memphis, Tenn.: National Cotton Council of America.

USDA-ARS. 1963. Pink bollworm kill with improved gin equipment. Production Res. Report No. 73 in cooperation with Texas Agric. Exp. Sta., Washington, D.C.